PLEXOS® for Power Systems
Electricity Market Simulation

USBR PLEXOS® Demo

November 8, 2012

Who We Are

- PLEXOS Solutions is founded in 2005
- Acquired by Energy Exemplar in 2011
- Goal
  - To solve the challenge problems facing the energy industry by providing simulation and optimization software and consulting services
- People
  - All principals have over 20 years simulation software development and consulting experience
  - All principals have Master degrees or Ph.D. in the engineering, economics and mathematics fields
- Three business areas
  - Support to the Power Market Simulation Software PLEXOS
  - Information Service: Daily WECC Term forecast
  - Consulting

PLEXOS Applications

- PLEXOS is used by ISOs, utilities, generators, consulting firms and governmental agencies for:
  - Operations
    - Day-ahead generation scheduling (unit commitment and economic dispatch) to minimize cost or maximize profit
    - Variable energy resource integration analyses
  - Planning and Risk
    - Integrated resource planning
    - Utility planning and energy budgeting
    - Portfolio risk evaluation
  - Market Analysis
    - LMP and AS market price forecast
  - Transmission (Network) Analysis
    - Economic transmission expansion
    - CRR (or) FTR valuation

About PLEXOS

- PLEXOS is a MIP-based next-generation energy market simulation and optimization software
  - Co-optimization architecture is based on the Ph.D. work of Glenn Drayton*
  - Advanced Mixed Integer Programming (MIP) is the core algorithm of the simulation and optimization
  - Foundation for the mathematical formulation of the New Zealand, Australia, Singapore and ISO day-ahead markets in the US and Canada
  - PLEXOS licensed in United States, Europe, Asia-Pacific, Russia, and Africa (17 countries, about 100 sites)

* G.R. Drayton. *Coordinating Energy and Reserves in a Wholesale Electricity Market*. University of Canterbury, New Zealand, 1997.

PLEXOS Algorithms

- Co-optimize thermal, hydro, energy / reserve / fuel / emission markets and contracts
- No iterations, no heuristics.
- User defines business constraints
- Intra-hour interval optimization
- Results can be independently audited *i.e.* simulation engine is not a black-box
- Naturally provides physical (primal) as well as financial (dual) output *e.g.* provides information on shadow prices which can be of crucial for your operating and planning decisions

Solving UC/ED using MIP

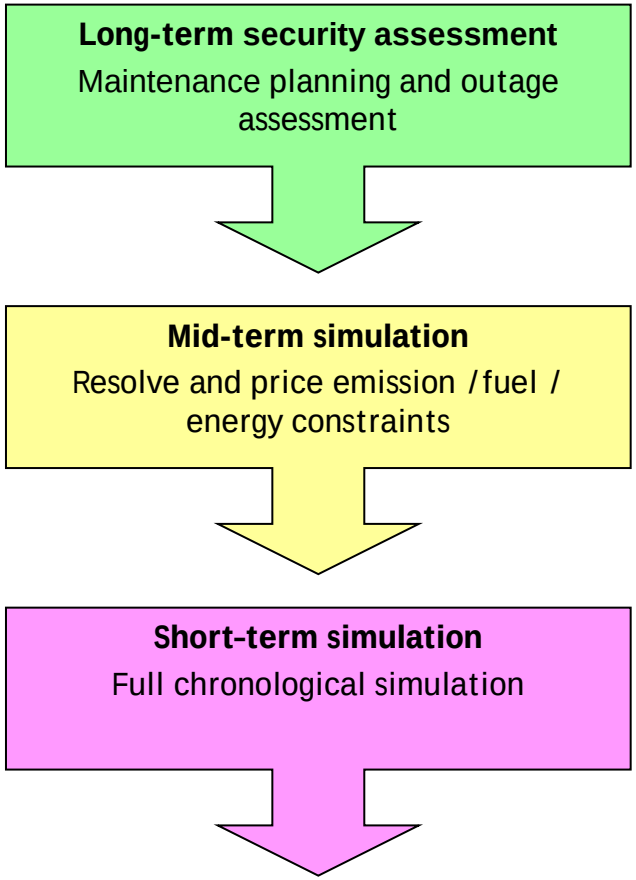
- Unit Commitment and Economical Dispatch can be formulated as a linear problem (after linearization) with integer variables of generator on-line status

Minimize Cost = generator fuel and VOM cost + generator start cost
+ contract purchase cost – contract sale saving
+ transmission wheeling
+ energy / AS / fuel / capacity market purchase cost
– energy / AS / fuel / capacity market sale revenue

Subject to

- *Energy balance constraints*
- *Operation reserve constraints*
- *Generator and contract chronological constraints: ramp, min up/down, min capacity, etc.*
- *Generator and contract energy limits: hourly / daily / weekly / …*
- *Transmission limits*
- *Fuel limits: pipeline, daily / weekly/ …*
- *Emission limits: daily / weekly / …*
- *Others*

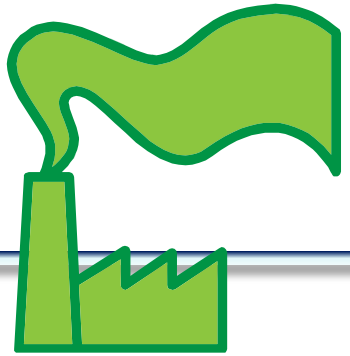
Integration of Mid- and Short-Term Constraints



- PLEXOS includes three integrated algorithms:
  - Long-term security assessment
  - Mid-term simulation
  - Short-term simulation
- Security, mid-term and short-term considerations are seamlessly integrated
- Mid-term simulation decomposes medium-term fuel, emission, and energy constraints for the short-term simulation

Detailed Generator Modeling

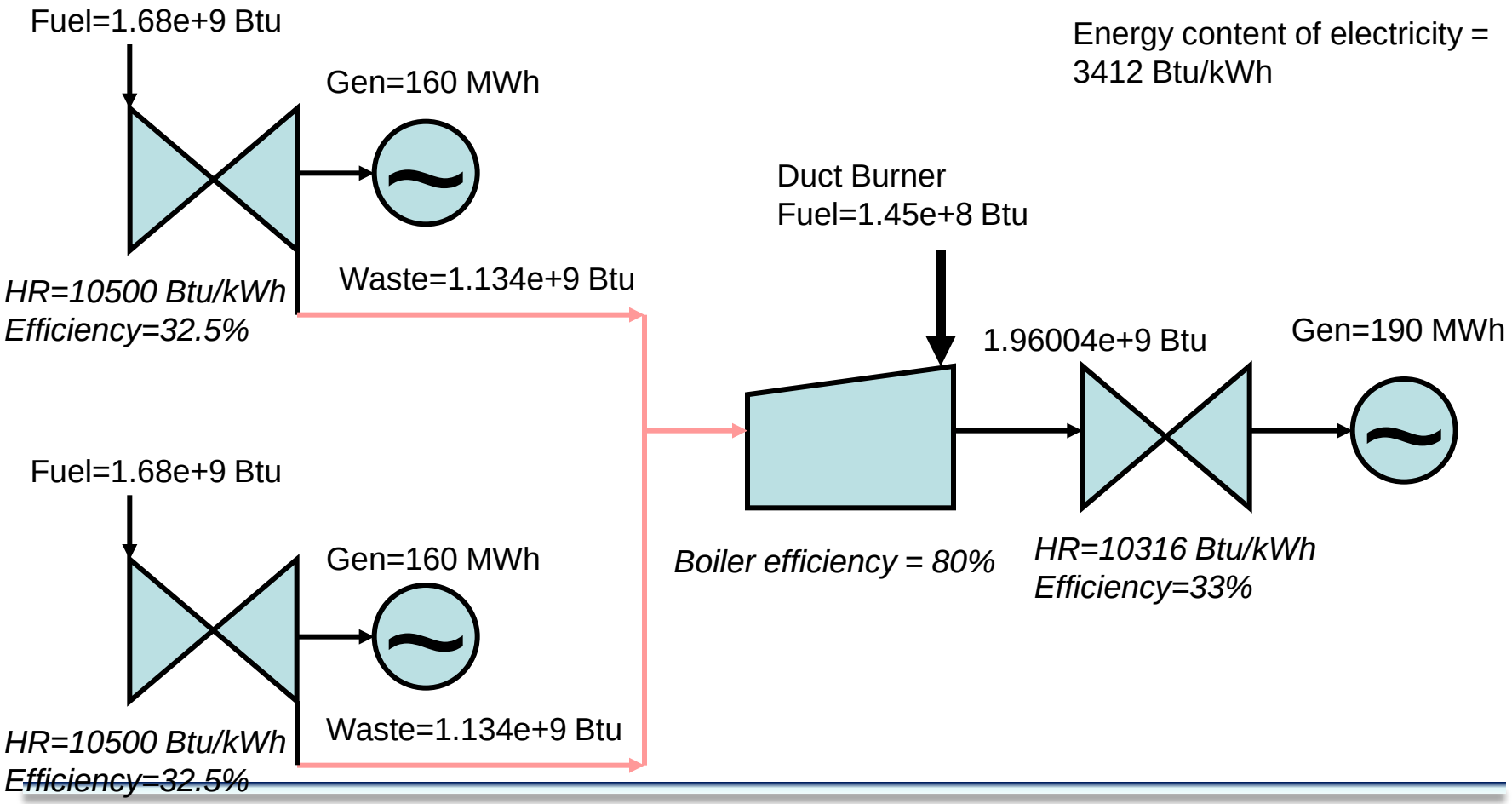
- General chronological constraints modeled, i.e.,
  - Minimum up and down time
  - Ramp up and down rate
  - Minimum capacity with hourly economic or must-run status
  - Reserve (regulation up/down, spinning and non-spinning) provision capacities
  - Start cost as a function of number of hours being down
  - Forbidden operation zone
- User-specified fuel mixture / mixture ranges or model-determined fuel mixture
- Heat Rate as a function of fuel types
  - Average heat rate for multiple loading points
  - Incremental heat rate for multiple loading points
  - Polynomial fuel-generation IO curve
- Emission rate with removal rate
- Initial commitment and dispatch status



Combined Cycle Modeling

- Component modeled individually
  - Combustion Turbine (CT)
  - Heat Recovery Steam Turbine (HRSG)
  - Steam Turbine (ST)
  - Duct Firing
  - Thermal load (cogeneration)
- Components tied together through linear or piecewise linear constraints
- Components optimized simultaneously with MIP algorithm

Combined Cycle Modeling, continued



Detailed Fuel Modeling

- Hourly fuel dispatch prices versus fuel accounting prices
- Tax by fuel
- Transport charge by generator
- Hourly / daily / weekly / monthly /annual fuel lower and upper limits
- Take-or-pay fuel contracts with take-or-pay price
- User-defined pipeline limits (using user-defined Constraints) and hourly burner tip limits
- Trade with fuel markets

Detailed Emission Modeling

- Emission rate by fuel or by generation or both
  - Emission rate by generation for multiple loading points
- Emission dispatch price versus emission accounting price
  - Dispatch price is automatically included in generator dispatch cost
  - Accounting price is used for production costing
- Hourly / daily / weekly / monthly /annual emission cap (using user-defined Constraints)
- Emission cap by (sub-)region or by (sub-)fleet
- Trade with emission markets or hard cap or both

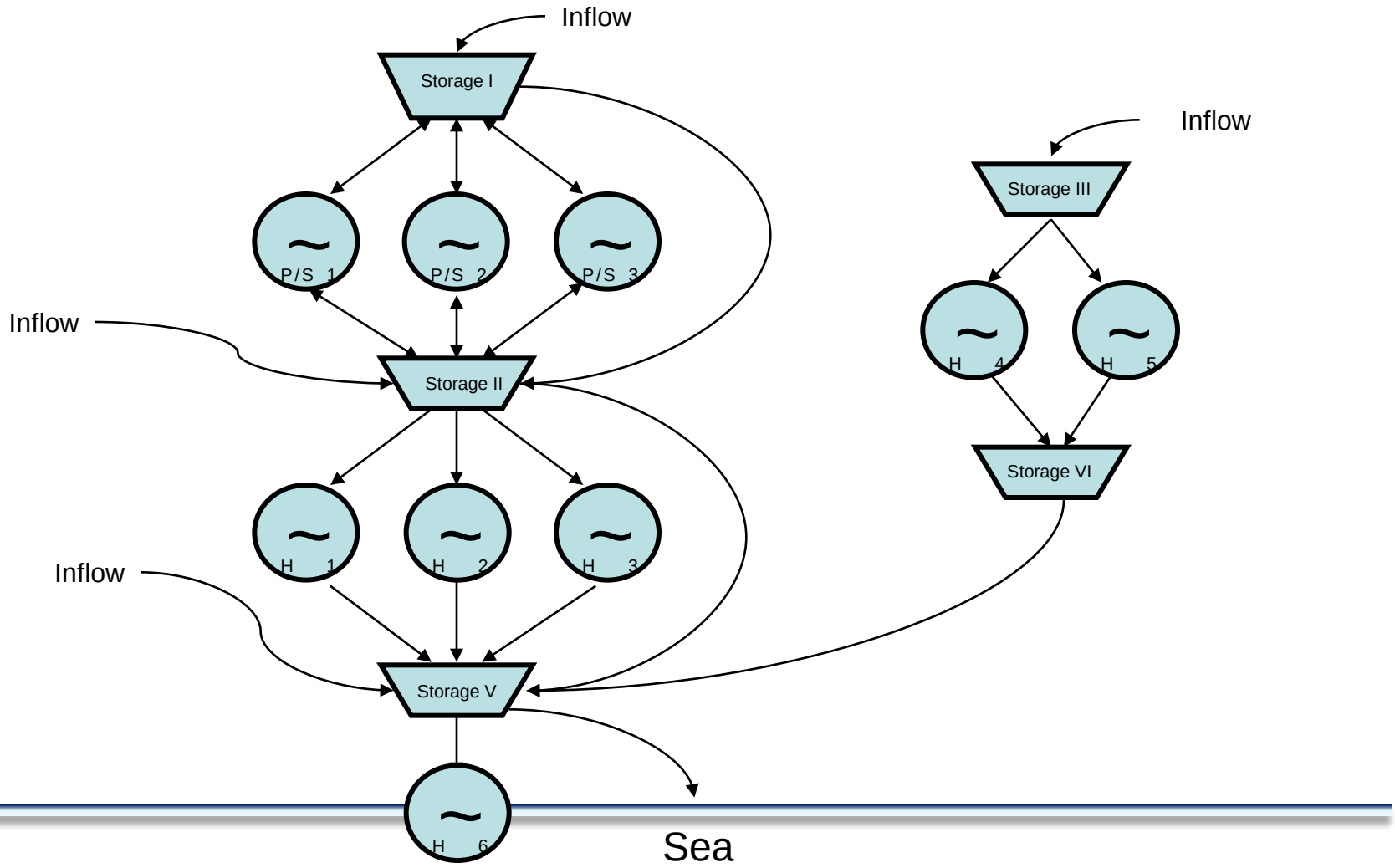
Detailed Energy Contract and Transmission Modeling

- Off-system purchase or sales
  - Hourly volumes and prices
  - Fixed cost and fixed energy charge
- Bilateral contracts with both delivering and receiving parties modeled
- Call or put options with strike prices
- Transport or DC-OPF modeled
  - Line limits
  - Interface limits
  - Losses
  - Wheeling charges

Cascaded Hydro Systems

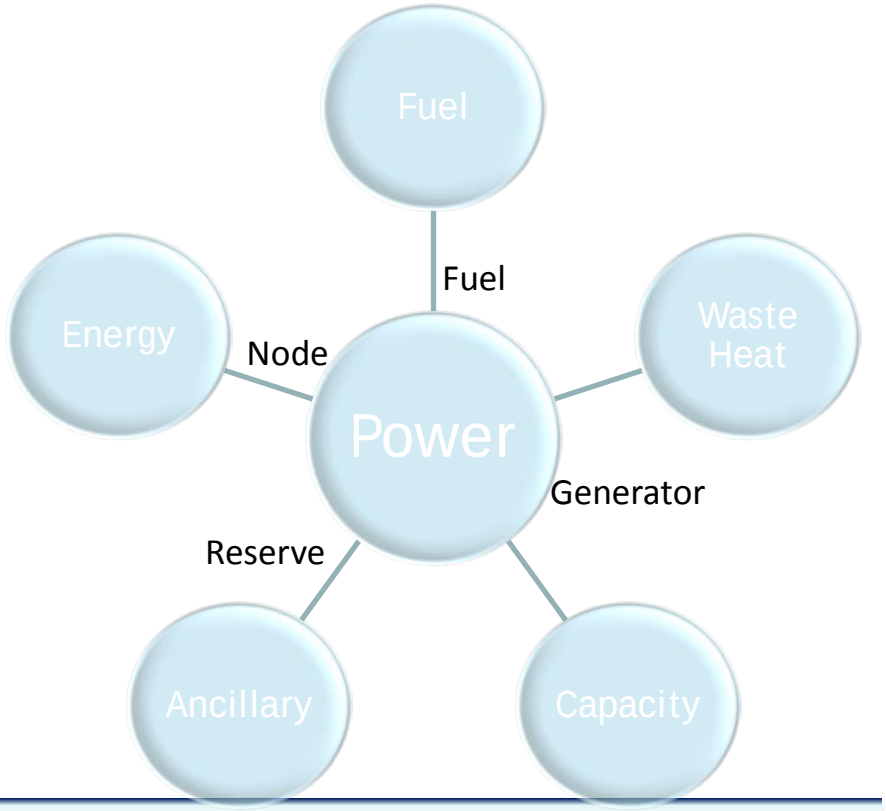
- Reservoir
  - Natural Inflow (AF/h)
  - Initial/Max/Min storage (AF)
  - Connecting waterway, generators
  - Storage target (AF)
  - Water value ($/AF)
- WaterWays
  - From a reservoir to another reservoir or “to the sea”
  - “Max flow” and “Min flow” in AF/h
  - Flow ramp rate “Max Flow Delta” in AF/h/h
  - Flow delay: “Traversal Time” in hour
- Hydro and P/S generators
  - Water efficiency as a function of generation load points
  - Different cycle efficiencies or ratings for different units

An Example of Cascaded Hydro System



Market

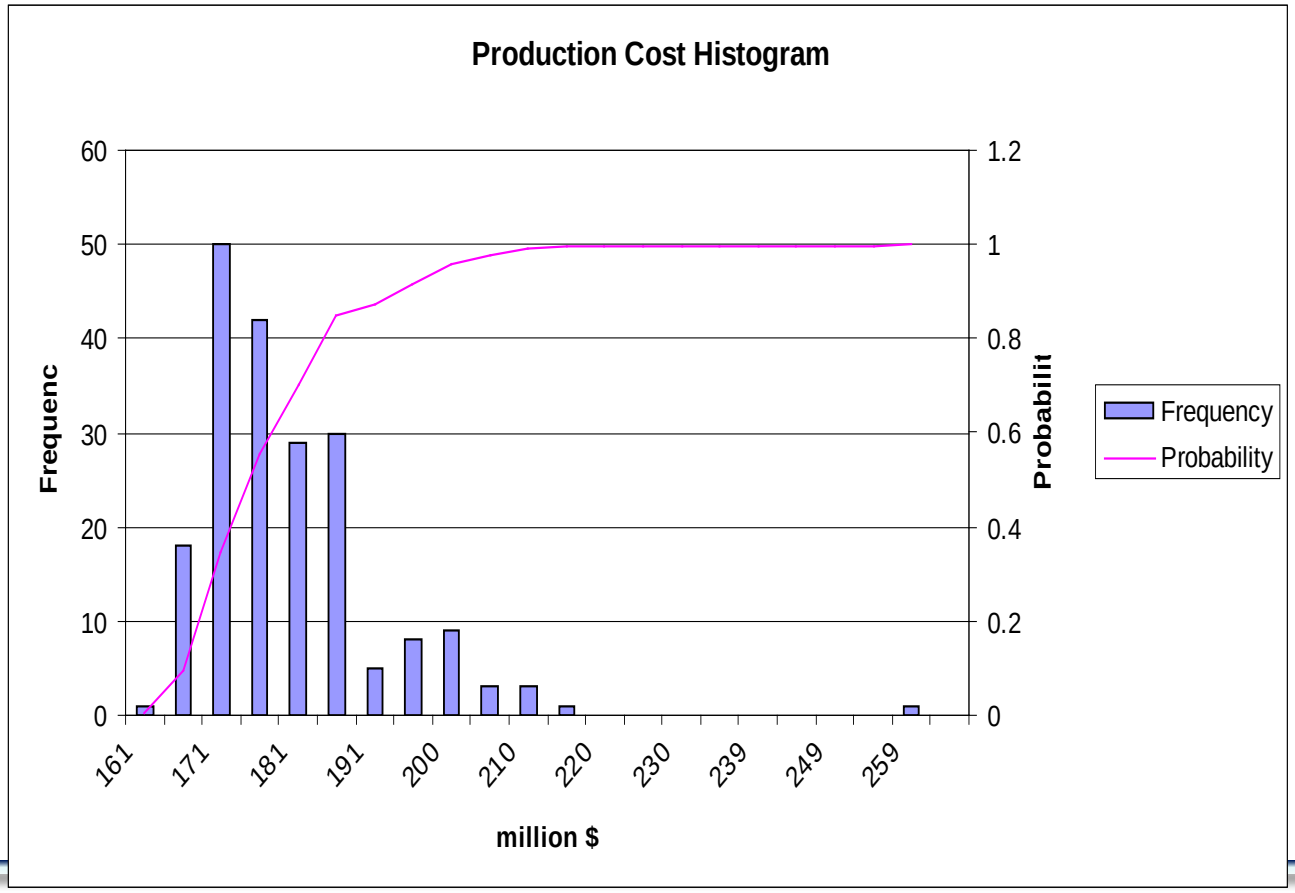
- Markets:
  - Energy markets: Exogenous power markets are connected to one or more transmission nodes. Trades to and from the energy market are made at these buses.
  - Fuel: Arbitrage between a fuel contract and a spot fuel market.
  - Heat: Waste heat co-optimization for CHP plants: Wasted heat can be offered to Heat market objects.
  - Reserve Markets: Reserve requirement can be taking/provided by external markets.
  - Capacity: Generators receive revenue from the capacity as a function of their availability



Stochastic Capabilities

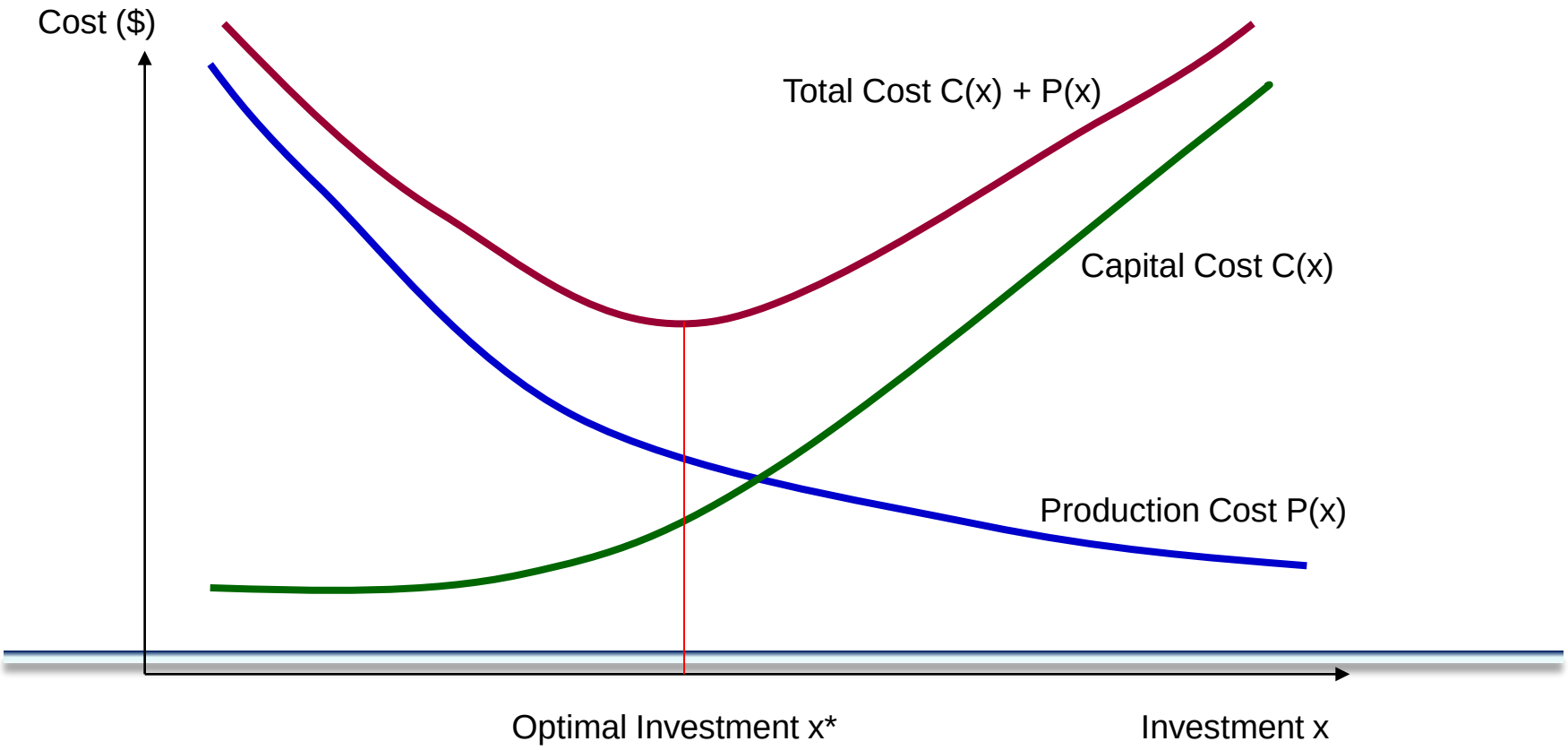
- Any simulation variable can be treated stochastically provided data are available
  - Endogenous sampling
    - Model-generated samples for given distribution
  - Exogenous sampling
    - User-specified samples
  - Stochastic sample correlation

Net System Production Cost Distribution



LT-Plan: PLEXOS for Integrated Resource Planning

- Objective: Minimize net present value of forward-looking costs (i.e. capital and production costs)



New Addition/Retirement Candidates

- Hydro
- Wind
- Geothermal
- Fossil
- Transactions
- Demand side participation
- Transmission augmentations

LT Plan: Constraints

- Investment Constraints
  - 10 – 30 year horizon
  - Minimum zonal reserve margins (% or MW)
  - Maximum reserve margins (optional)
  - Inter-zonal transmission expansion (bulk network)
  - Resource addition and retirement candidates (i.e. maximum units built / retired)
  - Build / retirement costs
  - Age and lifetime of units
  - Technology / fuel mix rules
- Operational Constraints
  - Energy balance for each TOD and each month
  - Ancillary Service requirements
  - Power flow limits
  - Resource limits: energy limits, fuel limits, emission limits, etc.
  - Others

A Portfolio Example